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ABSTRACT

The application of history of science to inform the design/curriculum, implementation/instruction and learning/assessment of science education is a process full of choices. What history and whose history to select and for what purposes ultimately defines the models of curriculum, instruction and assessment employed. Three organizational approaches for using history of science are examined: (1) A "How did we come to know and believe?" Scientific thema approach; (2) A film/video re-enactment approach focusing on key conceptual issues and on critical questions; and (3) A critical examination of competing explanations from modern history of science (1850 to present) approach focusing on epistemic reasoning. Respectively, the approaches represent the application of history of science in a university course sequence for non-science majors, as a context for teaching science concepts and images of science in Key Stage 3 (UK) or Middle School (USA), and a framework for engaging learners in scientific inquiry. The author participated in the development of each of the approaches. A description of each approach precedes a critical review of the use of history of science in science education. (Contains 35 references.) (Author)

Using and Abusing: Relating History of Science to Learning and Teaching Science

by

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Abstract

The application of history of science to inform the design/curriculum, implementation/instruction and learning/assessment of science education is a process full of choices. What history and whose history to select and for what purposes ultimately defines the models of curriculum, instruction and assessment employed. Three organisational approaches for using history of science are examined: (1) A "How did we come to know and believe . . .? scientific thema approach; (2) A film/video re-enactment approach focusing on key conceptual issues and on critical questions; and (3) A critical examination of competing explanations from modern history of science (1850 to present) approach focusing on epistemic reasoning. Respectively, the approaches represent the application of history of science in a university course sequence for non-science majors, as a context for teaching science concepts and images of science in Key Stage 3 (UK) or Middle School (USA), and as a framework for engaging learners in scientific inquiry. The author participated in the development of each of the approaches. A description of each approach precedes a critical review of the use of history of science in science education.

Introduction

The confluence of history and philosophy of science is often located with the publication of Thomas Kuhn's critically important book The Structure of Scientific Revolutions (1962/1970). Here Kuhn argues for a model of the growth of scientific knowledge that challenges the received view of the status of scientific knowledge. Scientific knowledge is not cumulative, there are occasions when modification, adaptation and/or outright abandonment of core theoretical and methodological beliefs occur. Kuhn's thesis, simply stated, is that the accumulation of anomalous data and information, where anomalies represent "a persistent discrepancy between observation and theory" (Brush, 2000), begins to challenge the status of normal science knowledge, beliefs, claims and activities. For Kuhn this set of ideas and commitments constitute the disciplinary matrix of a domain of science. Scientists enter periods of revolutionary science for the purpose of reconciling anomalies and in the process spawns new ideas and commitments that alter the disciplinary matrix.

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Given the theme of this conference, I think it is appropriate to point out for those individuals who may not know, that the development of Thomas Kuhn's ideas about paradigms, incommensurability and about science shifting between normal and revolutionary periods of inquiry occurred while he was working on a science education curriculum development project. Namely, The Harvard Case Studies in Science Education (Conant, 1957), directed by James Conant, then president of Harvard University. The spirit of science education at Harvard at the time is perhaps best demonstrated by the fact that it was while engaged in the preparation of materials for a case study that Thomas Kuhn began to develop the ideas for this seminal work The Structure of Scientific Revolutions.

As a science educator, I find this confluence of events so very fascinating for it explains so very much about the role history of science has come to play in American science education. Again, a bit more context. The Cases were being developed in the 1950s for the purpose of providing an alternative yet meaningful science education for the liberal education of undergraduate students who would not be majoring in a science. The names of some of the individuals at Harvard then working on the Cases and on other curriculum development efforts (e.g., Harvard Project Physics, see Holton, 1978) include such luminaries as Thomas Kuhn, I.B. Cohen, Gerald Holton and Stephen Brush in the history of science and Fletcher Watson, Leopold Klopfer, James Rutherford, William Cooley, and Jack Easley in science education. Now understand, that this collection of scholars were working on science curriculum reform issues at precisely the time that science curriculum reform became a national and international agenda. Just a mile or two down the road from Harvard, a group of physicists at MIT were setting in motion the development of the first of many National Science Foundation (NSF) funded projects – Physical Science Study Committee (PSSC) – that would adopt a science for scientists' approach. The Harvard group had serious concerns with this approach questioning whether it was a significant education objective.

The role of history of science in science education in the USA has been contested and examined ever since the NSF curriculum development period. Klopfer (1969) outlines a strategy for using the case history approach in secondary schools. Russell (1981) asks us to consider what and whose history we choose to teach, and how we choose to teach it. Brush (1974) warns us of the "x-rated" accounts history of science can bring to students' studies of scientific method. Rutherford and Ahlgren (1990) include history of science at the high school level (Key Stage 4) level only in the AAAS Project 2061 reform proposal. Allchin (1995) guides us in "How *Not* to Teach History in Science". Brush (2000) carries out a small examination of physics textbooks to discover that certain important details are historically wrong. He makes a plea that science textbook writers should take into account historical research.

The purpose of this paper is examine some of the ideological and theoretical clashes that occur when history of science is used as a framework for designing curriculum, instruction and assessment models. Within a discipline – science education or didactic of science – that draws upon a diverse set of theoretical perspectives (e.g., philosophy, psychology, pedagogy), trade-offs between such frameworks are inevitable.

The early clash between Harvard and MIT foreshadows, I will argue, the ongoing and continued clashes that emerge whenever history of science is invoked as an organising tool. What history and whose history to select and for what purposes ultimately defines the models of curriculum, instruction and assessment employed. The purpose of this paper is to briefly examine 3 organisational approaches for using history of science, ones with which I was personally involved, and to examine the tensions that arise when history meets philosophy, psychology and pedagogy.

My three involvement's were being a member of staff for a full-year university course sequence at Hunter College in New York City, serving on the advisory board for the NSF funded "Mindworks" project, and directing my own curriculum development efforts. Following a brief elaboration on the MIT/Harvard clash, the paper will discuss each of the my three forays into using history of science in science teaching and curriculum design. The paper concludes with summary statements and perspectives about issues of using and abusing history of science in educational contexts.

What place History of Science in Science Education?

Following World War II, the National Science Foundation (NSF) was established. NSF was charged with guaranteeing that the USA's potential in science research and science education would be exemplary. Under the direction of practising scientists, the first curriculum development grant was award to the Physical Science Study Committee in 1956. The position was taken that the summer institutes NSF was offering to science teachers since 1951 would not have any impact if the teachers were using outdated textbooks and curriculum materials. By 1964 NSF was supporting seven elementary/junior level (Key Stages 1,2, and 3) projects and five secondary (Key Stage 4) projects. By 1966, there were 26 projects (19 science and 7 maths) receiving NSF funding. Being the first co-ordinated and funded effort the PSSC project established the procedures all other curriculum projects would ultimately follow. Typically, project teams were composed of scientists, teachers, and administrators. It was clear from the very start though that the scientists were in charge (Welch, 1979). Individual projects were directed by prestigious scientists, co-ordinated by advisory boards of prestigious scientists, and written by scientists. Useful overviews of the NSF science education curriculum reform period can be found in DeBore (1991), Duschl (1990), Jones (1977) and Welch (1979).

The role of the teachers and administrators in the development of curriculum was primarily to provide feedback to the scientist-writers. Once a curriculum draft was ready, it would be distributed to teachers in test classrooms across the nation. Based on the trial run of the materials, changes would be made. More often than not, however, teacher's feedback had very little effect on subsequent versions of the curriculum (Jones, 1977; Welch, 1979).

A critical factor, then, in understanding the history of NSF curriculum projects is the dominant and decisive role members of the scientific community played. This role had a significant effect in determining the focus of the curriculum – science for scientists.

But as early on as 1958 the history of science group at Harvard raised concerns about whether the type of science education being proposed by PSSC was what public education wanted or needed.

In 1959 the Harvard Educational Review dedicated a major portion of one issue (V 29, N1) to reporting the papers delivered at a symposium on the PSSC program. Given the changes in science education taking place at Harvard University, the critical reactions were quite predictable. Initial reactions by educational researchers to PSSC's curriculum were quite critical of the dominant emphasis on scientific method rooted in experimentation and not in educational theory (Easley, 1959). The plea was for an integration of philosophy, logic, statistics, and psychology frameworks that would inform the scientific knowledge and processes being packaged into PSSC and other NSF curriculum efforts. A particularly poignant issue was whether the teaching of the scientific method by getting students to operate as scientists was a significant educational objective. The Harvard team (Holton, 1978) went on to receive their own NSF funding and developed Harvard Project Physics for high school students. Other history of science and science teaching efforts include the college level textbook Introduction to concepts and theories the Physical Science (Holton & Brush, 1952/1969) and an adaptation of Conant's Harvard Cases History of Science Cases (Klopfer & Cooley, 1961) for use in secondary level science programmes.

For a variety of reasons, some of which are similar to those I will raise below, the infusion of history of science into the teaching of physics never caught on. While evaluation data clearly showed positive gains in students attitudes toward science and understanding of the nature of science (Welch, 1973), the gains on physics achievement tests, the benchmark used by elite universities to admit students to physics programmes, were minimal. The purpose of a science education was on the line then and still is today – science for all v science for future scientists.

Hunter College – Foundations of Science

With support from the Andrew W. Mellon Foundation and under the direction of Ezra Shahn (1988), the Foundations of Science course was designed as a 1-year introductory course for non-majors. The goal of the course is to provide students with the background knowledge needed to appreciate "how we know what we know and why we believe what we believe". I was brought to Hunter College to become the science educator on the team which comprised myself, Professor Shahn in biology, a professor of chemistry, a professor of physics and a professor of anthropology. My roll was to evaluate the programme models for curriculum, instruction and assessment as well as evaluate student learning. For the former task I attended all lectures, taught a lab section, graded student essays, and participated in all team meetings. For the later task, I set up a series of interviews over the course of the course with a number of target students.

The interviews revealed quite early on that the students did not know what to learn. That is, there was a confusion about knowing the history and knowing the science. The course is designed around three big ideas that are still a prominent component of our contemporary scientific view of nature. The first was a physics focused question – How did we come to know motion and forces that govern planets and objects on our planet? The second was a chemistry focus – How did we come to know that matter is particulate in nature? The third focus both geological and biological – How did we come to know that the Earth and life on Earth have a history?

The course was designed to have both lectures and labs. Final grades are based on two exams, four or five essays, and laboratory work. The essays were short 4-5 page long assignments with revisions required. The laboratory exercises were frequently replications of historical experiments (e.g., Galileo's inclined plane experiment using a water clock). Many of the readings were from original sources supplemented by either professor's course notes or chapters selected from various history of science anthologies. The inclusion of the essays with revisions in the course speaks to the importance the course designers held for language and reasoning development. The inclusion and design of the lab exercises reflects the designers' commitments to observing and doing science (See Shahn, 1988 for a more complete description of the course and of the designers' guiding frameworks).

From my position of lab instructor and grader of essays, I quickly began to see that students were not using the evidence from the labs and from the history readings and lectures to reason about the "How" path of changing concepts and evolving explanations. An age old problem – students making links between lecture and lab. The problem, I felt, was the decision to base the labs on the "learning cycle" approach. This is a Piagetian model of instruction in which students explore, analyse, and apply knowledge. On theoretical grounds, using the learning cycle also commits one to a hypothetico-deductive(H-D) philosophy of science. The idea was that this discovery mode would replace the didactic mode, particularly in the labs where the lab instructors were informed to provide non-intrusive guidance.

The students were not discovering. The learning of concepts employing the learning cycle did not fit nor keep pace with the evolving historical dynamics of observation and theory changes. Sorting out the history and sorting out the science and how to bring them all together was an enormous challenge for students. Adopting a model of instruction based on a theory of learners abilities (e.g., concrete v formal operational thinkers) and on a context of justification as opposed to instructional models based on theories of learning strategies (e.g., cognitive problem-solving theory) and a context of discovery, was in my opinion a serious error. In my opinion, the models of psychology and philosophy did not cohere with the historically based curriculum that was telling the story of theory restructuring and development.

The students were just inundated with concepts, dates, names, instruments, evidence, etc. and they thought it was all equally important to know and to learn. It wasn't. History of science was the context within which the students were to learn important concepts and how these concepts came into existence. Students needed guidance about what to a pay attention to and strategies for co-ordinating information from the lectures for use in the labs. It was my learned opinion that the historical laboratory approach would need to be adapted to accommodate psychological theories of learning which embraced knowledge restructuring and philosophical views of theory change (e.g., Kuhn, Lakatos, and Laudan).

Southwest Regional Laboratory - Mindworks

Under the direction of Barbara Becker and with support from NSF, Mindworks represents a series of eight physical science instructional modules for use in secondary schools. The goals of the modules are (1) to motivate students with low interest in science, (2) to invoke conceptual change in students understanding of the structure and workings of the physical world, and (3) to enhance understanding of the process and culture of scientific activity.

Building on her commitment to using original historical materials for teaching secondary and college science (Becker, 1992), Dr. Becker sought to bring this approach to the design of curriculum materials for slightly younger children grades 7-9 in the US or Key Stage 3 in the UK. Her position is that "exposing students to the social construction of scientific knowledge through historical episodes that emphasise the intellectual struggle involved in developing key physical science concepts will help them articulate their own theories about the world and recognise a need to change the form and structure of these theories" (Becker, 2000, 270). Not unlike the position proposed by Nancy Nersessian (1992), history of science would be used "as a heuristic device to anticipate and address alternative conceptions in science across the grade levels" (Becker, 2000, 270). Historical examples would be used to integrate content, context, and method.

Careful not to fall into the trap of providing quasi-history, pseudo-history or simplified history, Becker did set out to capture a simplified history of science that would illuminate the subject matter while not abusing the history. Her endeavour is to expose students "to the social nature of scientific knowledge via a mix of observation and discourse" (Becker 2000, 272). The NSF funding was used to create 8 professionally produced short video dramatisations focusing on core concepts in the physical sciences as well as raising social, philosophical and/or political issues that will interest students.

Once the videos were written and produced, teachers and staff worked together to develop the full package of curriculum units, lesson plans and student activities. The teachers were provided with original historical documents and summaries of biographic and historical information and asked to develop activities through writing, debates, and discussions that would immerse the learners in the work of scientists and inventors.

The tension that arose, not unlike the Hunter course, was the kind of science investigation activities being developed for some of the modules. The Mindworks modules had to meet the California State guidelines. This meant, like here in the UK, the inclusion of investigations or practical work in the curriculum units. Teachers were selecting investigations that would quite clearly work against students seeing the social nature of science. Standard already-in-use cook-book style investigations were being proposed rather than the more effective design based investigations like that developed for the module on George W. Ferris' plans for the observation wheel at the 1893 Chicago

World's Fair. Here students would design their own Ferris Wheels and test forces acting on their structure. Science lessons with fixed outcomes do not engender debates and discussions about the nature of science. There are also compelling arguments that these sorts of science lessons do not promote conceptual change learning.

The culprit to me seemed to be the pressure of time and the pressure of politics. There wasn't enough time to developed project-based or design-based activities for each of the modules nor did the existing curriculum framework allow instructional time for such extended inquires. The issue for me was that goals of the project would be compromised. While the motivation and cultural goals , see 1 and 3 above, would be the purview of videos and original historical documents and the writing, debating and discussing activities around these, the goal of concept learning and conceptual change, number 2, would be delegated to the investigations demonstrating concepts. The integration of history of science with science teaching contained tensions. A coherent educational theory that functioned across curriculum design, instructional strategies and assessment frameworks seem to be missing. The evaluation of the project is presently underway. I hope I am proved wrong because the history of science materials Barbara Becker has produced are, in my opinion, excellent.

Causes of Earthquakes or How *Not* to Teach History of Science

Let me now turn the microscope on myself. At the Third IHPSST conference held in Minneapolis, MN, USA, Douglas Allchin (1995), presented a paper that uses one of my curriculum design approaches as an example of how not to teach history of science. Let me first outline the approach and then his criticisms.

A major area of my research has been understanding the role of explanation and theories in science education. Duschl and Wright (1989) sets out the problem – teachers do not consider the structure of scientific theories in their planning or teaching. Duschl (1990) sets out some strategies for addressing the problem. The basic proposal is that philosophical models that account for theory change and evaluation can be used as strategies and frameworks to inform the design of curriculum, instruction and assessment models. Over the years, we have come to call these pedagogical models Growth of Knowledge Frameworks (Duschl & Erduran, 1996).

Inspired by Stephen Brush's work on modern history of science (1988), I hit upon the idea that getting teachers to examine with their students contemporary competing explanations for the same phenomenon would be an effective way to teach about the nature of theory change and the dialectic processes between observation and theory. A focus of my research has been developing students epistemic reasoning in general and the evaluation of knowledge claims in particular.

Using both contemporary and historical sources from textbooks and popular science magazines and books, I located 5 competing explanations for the causes of earthquakes proposed over the last 100 years. A complete description of the original activity can be found in Duschl (1987). The five explanations, in chronological order, are (1) gravitational forces of the moon and sun (2) barometric changes, (3) isostatic (floating) movements of mountains, (4) plate tectonic theory, and most recently, (5) rising methane gas. These were provided in original text formats and in summary formats. The first part of the activity was to determine the explanation for earthquakes from each source.

The context for evaluating each of the explanations was the focus of the second activity. Students were guided to ascertain the pattern of earthquakes found in a 10-year data base map produced by the US Geological Survey. The map presented both the epicentre (surface location – position on map), the focus (depth below surface – red shallow, green middle, blue deep), and intensity of earthquakes - those > 7.0 on Richter scale appear as circles rather than dots.

Employing Laudan's (1977) general problem solving criteria for evaluating research programs, namely empirical and conceptual problem solving, students were guided to consider the extent to which the evidence supported or refuted each explanation. Thus, for example, the barometic pressure explanation does not account for earthquakes at the bottom of the ocean floor nor does it explain deep focus earthquakes. Five criteria based on the location and patterns of earthquakes were used to evaluate the empirical adequacy of the explanations. These criteria reduced the pool of options to two since both explanations 4 and 5 had equal empirical adequacy. The last part of the activity then turn to conceptual problem-solving tasks. How did the models and theories scientists hold about the Earth help determine the most plausible explanation for earthquakes? The fact that the jury is still out on this one suggests that both explanations must be considered.

The framework of using competing explanations was used by my graduate students as a context for applying HPS to science teaching. The students designed curriculum units on theories of breast cancer treatment, theories about life on Mars, theories about origin of the moon, and theories about the interior of the earth (Kachman & Sutton, 1993). For this collection, the GKF used was Giere's Theory Testing Argument Scheme (see Duschl & Erduran, 1996). In brief, the Giere Framework uses an argumentation structure to frame both the background knowledge and initial conditions used to propose a theoretical hypothesis or model. The framework is there for teachers to use as a planning device and students to use as learning device.

Allchin took issue with the reconfiguring of history. That is, there was never an instance in the history of science when geologists were actually confronted with this mix of explanations, "no one in history sat down to consider these five theories all at once" (Allchin, 1996; 16). While Allchin recognises the value of the exercise in terms of getting students (1) to appreciate that different explanations of the same phenomenon are possible, (2) to consider how theories are rooted in certain assumptions, and (3) to engage in the higher cognitive reasoning skills associated with the evaluation and interpretation of knowledge claims, he takes issue with several things.

> The exercise reconstructs rather than simulates science. The exercise is further reconstructed – or artificially contrived – in its pre-established data set (Part 2). Why this data? Students receive only a small part of evidence is relevant, once they know the multiple explanations; and the data is largely significant only from the current theoretical perspective. (Allchin, 1996; 16).

Douglas goes on to critique the decision to provide students with the data and with the criteria/questions/standards to judge the explanations as an example of not being concerned with the process of history but only its product. He writes:

> The problem with teaching through rational reconstructions is that the history . . . is backwards. The aim is to find the route to (from?) the final answer. We should, instead, be tapping history to model the blind forward-moving context of science. The generation of hypotheses, the search for relevant information, the design and critique of experiments, the elaboration of alternative explanations, the struggle with experimental anomalies – all the elements of scientific discovery – cannot be taken for granted. There is more to science than just justifying the final outcome – or assuming that it is correct (ibid., p 16-17).

There is much that I agree with here. And with a full semester in college classes or 6 to 8 weeks in a high school class it would be possible to design the curriculum model he suggests. But the reality is that typical classrooms do not address theory or explanation evaluation, teachers have not been provided in their training with pedagogical, philosophical and/or psychological models for addressing the evaluation of explanations, and schools do not provide the resources for students to collect certain types of data (e.g., earthquake data). On epistemic and cognitive grounds, the comparison of plausible explanations has merit. On historical grounds, the approach presents problems.

A Model-based view of Science Education

Shapere (1977) introduced the idea of domains of science as intellectual spaces where scientific activity and reasoning function across traditional disciplinary boundaries. Giere (1989) further develops these naturalised philosophy views into a model-based view of science. For Giere, theories are composed of sets of models and only the models have a foot in the real world. The connection between the models and the theories he asserts is non-linguistic in nature while the connection between models and the natural world is linguistic in nature and best understood in terms of cognitive processes. This account has the benefit of explaining the revisionary nature of knowledge claims within a modest realism framework.

The amelioration of the tensions between history of science and science teaching can, I think, be decided in terms of a model-based view of science teaching. We work in a domain that is informed by intellectual disciplines of history and philosophy of science, psychology, and pedagogy. Our models of philosophy, of psychology and of pedagogy need to come together and cohere. This union, if you will, will constitute a theory of science education. The adoption of cognitive frameworks to propose a cognitive model theory for articulating the design of science curriculum was first proposed by Merce Izquierdo and colleagues (Izquierdo, Cabello, & Solsona, 1992) and quickly developed into a comprehensive 'didactic theory' (Izquierdo, Sanmarti, Espinet, Garcia, Pujol, in review). Their didactic theory draws heavily from Giere's model-based view.

The adoption of cognitive models and decision making within human judgement, or more precisely cognitive structures and cognitive processes, as a mechanism to explain science shifts, Giere argues, the philosophical goal from the justification of scientific knowledge, processes and methods to an understanding of scientific knowledge, processes and methods. This semantic-realism model-based view(MBV) of science has the advantage of allowing one to talk about models "fitting" the world rather than of being truth statements about the world.

This global MBV perspective of scientific processes, has the advantage over rival instrumental-based and justification-based philosophies of science in that the MBV can embrace, where the others can not, the inherent variation and complexity of the natural world and cognitive processes that seek to make sense of that world. On these grounds I feel the MBV embraces the psychological human information-processing theory (Newell and Simon, 1972). This theory speaks of individuals developing models of reality to cope with the inherent limitations that exist when the task environment one encounters provides far too much information to process. Classroom teachers, as all professionals, must cope with this dilemma (Duschl & Wright, 1989). MBV can also embraces socio-cultural theories of learning (Wertsch, 1985) since both recognise the importance acquiring cognitive resources have for providing mechanisms which drive the development, evaluation and deployment of scientific thinking and judgements.

> These cognitive resources and interests, combined with various judgmental strategies, provide the *mechanisms* - the analogs of genetic mechanisms in organic evolution - which drive the evolution of scientific fields. And this evolution takes place in an "environment" of cultural and material resources required to support modern, high technology research . . . cognitive models represent some of the *mechanisms* by which various interests influence the evolutional development of scientific fields. The remaining enterprise is to work out the details of this process. (Giere, 1986; p 324., italic in original)

The agenda for aligning history of science with science teaching is one that requires consideration of coherent models of philosophy, psychology and pedagogy. The recent attention in educational research to investigating and understanding the design of learning environments (Bransford, et al; 1999) that support the development of cognitive resources, interests, judgmental strategies and mechanisms for the purpose of developing, in our case here, learner's scientific understanding, is, on my view, an enterprise quite similar to that proposed by Giere. So, too, is the need to "work out the details of the process" a similarity.

Clearly, history of science is a critical element in the model-based view of science teaching precisely because it is a critical element in the philosophical domain of the model. The historians of science and educational researchers at Harvard in the 1950s understood then that a proper model of science education needed to deal with an integration of philosophy, logic, statistics, and psychology frameworks. It needed to have an educational theory. My three personal stories show some of the complexities of the integration process when philosophical, psychological and pedagogical frameworks are at odds with each other. When such tensions exist, important details can drop out in the design and implementation processes. The 3 scenarios certainly mask or hide the diverse and successful ways that history of science has informed the design of science curriculum. However, for two disciplines that are both in the first century of belonging to academia, a great deal of progress has been made already. The historians of science are setting exemplary examples of working with educators to improve science education. We both benefit from recognising that each of our communities have comprehensive guiding conceptions and programmes of research. Let us continue to come together and discuss the problems and potential solutions.

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